GEOLOGIC EVALUATION OF TRENCH EXPOSURE

VOGTLE ELECTRIC GENERATING PLANT

August, 1984

GEOLOGY GROUP

GEOLOGIC EVALUATION OF TRENCH EXPOSURE

VOGTLE ELECTRIC GENERATING PLANT

August, 1984

GEOLOGY GROUP

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 EXECUTIVE SUMMARY

A construction trench has been recently excavated at the Vogtle Electric Generating Plant (VEGP) site. The trench exposes Tertiary Coastal Plain sediments containing a variety of small-scale deformation structures, including warped bedding, fractures, joints, minor offsets, clastic dikes, and injected sand dikes. The great size of the trench coupled with knowledge of underlying stratigraphy gained from prior geologic investigations at VEGS offers a unique opportunity to evaluate the origin of these Coastal Plain small-scale structural features.

The structural features are interpreted to be local phenomena related to dissolution of an underlying carbonate bed, the Utley Limestone, followed by one or more phases of plastic and brittle collapse of overlying Tertiary sediments. The collapse created depressions and folded bedding in the overlying strata. Fractures and joints are spatially associated with the depressions and resulted from brittle, tensional failure of consolidated and semi-consolidated sediment during collapse. Displacement along many fractures resulted from irregular differential settlement of blocks. Most displacements are normal into the subsiding depression and many fractures and offsets are continuously over the centers of depressions. The offsets are laterally and vertically discontinuous; none persist across the trench.

The sand dikes appear to result from plastic or liquid injection of loosely consolidated fine sand into the overlying, fractured, relatively

consolidated sedimentary rock. The sand probably mobilized in response to sudden increased overburden pressure during sediment collapse.

Clastic dikes resulted primarily from weathering and soil-forming processes preferentially enhanced along the pre-existing fractures and offsets formed during the collapse. Their present geographic distribution is controlled by the depth of weathering and paleosol development in the Coastal Plain sediments and by subsequent erosion of the land surface.

The Coastal Plain structural features exposed in the trench are not tectonic features nor are they indicative of regionally significant seismic activity. Orientations of the structures are locally consistent but vary widely from location to location both within the trench and within the surrounding area. Similarly, three-dimensional reconstruction of the fold structures indicates that they are local depressions superimposed on a nearly horizontal bedding surface and do not have laterally persistent axial trends characteristic of tectonic deformation.

Age of the structures is poorly constrained. They are younger than the Eocene and Miocene host sediment and older than overlying late Pleistocene or Holocene eolian sand. With the exception of clastic dikes, the structures are also older than a major erosional event that lowered the Miocene land surface up to 20 feet and a major weathering

event which produced a well-developed relict soil on the eroded Miocene surface. These two events occurred over an interval of at least 100,000 years suggesting that the pre-dating structures are middle Pliestocene or older image. Clastic dikes probably developed during the major weathering/soil-forming event and thus may be as young as 10,000 to 100,000 years old.

2.0 INTRODUCTION

Small-scale deformation structures are common in the Tertiary sediments of the upper Coastal Plain Province of southwestern South Carolina and northeastern Georgia. Clastic dikes, contorted bedding, fractures, joints, and small offsets have been observed by numerous investigators in varying degrees of development and preservation. Their general distribution in the upper Coastal Plain of this area is illustrated on the outcrop map of selected exposures prepared by McDowell and Houser (1983), who note that many additional exposures are also present.

Despite their widespread occurrence, the origin of these small-scale structures is poorly known. They have been variously attributed to seismic or tectonic activity (Siple, 1967; Howell and Zupan, 1974; Zupan and Abbott, 1975; Inden and Zupan, 1975, Seeber and Armbruster, 1981), to solution of underlying carbonate horizons and sediment collapse (Siple, 1967; Secor, 1980), and to weathering and soil-forming processes (Johnson and Heron, 1965, Heron, 1965; Heron and others, 1971). These varying

hypotheses reflect the possiblity that each structure may have a different origin, or that the origin of each structure may differ from region to region. In addition, the interpretation of origin has commonly been hindered by limited outcrop dimensions and by insufficient information on underlying stratigraphy. These limitations have restricted observation of the lateral and vertical continuity of the structures and the relationships of the structures to one another, to the host sediment, and to the underlying stratigraphy.

This paper describes a recently excavated, large trench-exposure of deformed Coastal Plain Tertiary sediments near the Vogtle Electric Generating Plant (VEGP), in Burke County, Georgia (Fig. 1). The trench trends N25°W and is over 900 feet long, 30 to 45 feet deep, and 25 to 40 feet across. Contorted bedding, fractures, joints, minor offsets, and two varieties of clastic dikes are well exposed in the trench walls (Fig. 2). The two varieties of dikes include both those previously described in the literature but which, as this study indicates, are not true clastic dikes (e.g. extraneous material emplaced into the containing host sediment either from above or from below), as well as a form of injected clastic dike not previously described in the literature of this area. In this paper, we retain the common usage of "clastic dikes" as a descriptive term for features similar to those described in the literature, while the injected clastic dikes are herein called "sand dikes" to simplify description and avoid confusion. The lateral and vertical dimensions of the trench permitted accurate determination of the

relationships of all the structures to one another and to the host sediment, while detailed mapping of both walls provided data for three-dimensional reconstruction and analysis of the structures. In addition, previous VEGP geologic investigations have accurately defined the subsurface stratigraphy at the site (Georgia Power Co., 1984).

The trench thus offers a unique opportunity to study the origin of Coastal Plain small-scale deformation. Our conclusion is that, at this locality, the contorted bedding, injected sand dikes, fractures, joints and small offsets are local phenomena that resulted from the dissolution of an underlying carbonate unit and subsequent collapse of overlying sediment. Clastic dikes formed by surficial weathering and soil-forming processes preferentially enhanced along these pre-existing fractures, joints, and offsets related to the collapse.

3.0 GEOLOGIC SETTING

The trench exposure is situated on the Atlantic Coastal Plain approximately 25 miles southeast of Augusta, Georgia (Fig. 1). It is approximately 4000 feet north of the VEGP site at latitude N33°9', longitude W81°41', and has been excavated for disposal of construction waste.

3.1 Local Stratigraphy

The Atlantic Coastal Plain sediments consist of poorly to moderately consolidated sand, silt, marl and limestone of Cretaceous to Quaternary

age which dip slightly to the southeast. The stratigraphy of these sediments at the site has been defined by previous drilling investigations at VEGP and includes in descending stratigraphic sequence Quaternary eolian sand, the Miocene Hawthorn Formation, the upper Eocene Barnwell Group, and the middle Eocene Lisbon Formation (Georgia Power Company, 1984, Figure 2.5.1-3). The eolian sand consists of brown, gray and white, very well sorted, subangular to subrounded, fine quartz sand. The Hawthorn Formation is typically a poorly sorted, red, yellow and tan clayey sand. The Barnwell Group contains a variety of laterally discontinuous marine facies but is predominantly a red, brown, yellow and buff, well to poorly sorted, fine to coarse sand and sandy clay. The Lisbon Formation is typically a yellow-brown to green, fine to coarse, glauconitic quartz sand with lenses of clay and limestone.

Approximately 75 feet beneath the surface at the trench site, the lower Barnwell contains the Utley Limestone. The limestone is 50 to 70 feet thick and consists of locally highly pervious, glauconitic, sandy coquina. Immediately underlying the limestone, an 80-foot-thick sandy marl aquiclude called the Blue Bluff marl is present in the upper Lisbon Formation.

Site exploration at VEGP has defined shallow depressions or sinks in the sediments overlying the Utley Limestone (Georgia Power Company, 1984). Isopach maps of the Utley Limestone drawn during these investigations indicate that the depressions result from dissolution and removal of

material from the Utley Limestone and are not the expression of deeper structures in the Blue Bluff marl or lower units. Overlying sediments have collapsed into the depleted areas creating depressions in both the overlying strata as well as occasionally on the existing surface topography. The underlying Blue Bluff marl maintains a laterally consistent elevation and is not deflected across the depressions.

3.2 Trench Stratigraphy

Coastal Plain sediments exposed in the trench include the Hawthorn Formation and the upper Barnwell Group, above the Utley Limestone. The limestone is not exposed. Late Pleistocene or Holocene eolian sand from 5- to 20-feet-thick overlies the Hawthorn and forms the upper part of the trench walls.

For the purposes of mapping and evaluating deformation structures, these deposits are divided into nine lithologically distinct informal units designated A through I in stratigraphically ascending order. These units are described in Table 1 and shown on the geologic maps of the trench walls in Figures 3 and 4. Tentative correlation of these units with the formally accepted stratigraphy described above suggests that Units A through G are part of the Barnwell Group, Unit H comprises the Hawthorn Formation, and Unit I is the Pleistocene or Holocene eolian sand.

3.3 Unconformities and Weathering Intervals

Two erosional unconformities and two, possibly three, intervals of weathering and soil-development are present in the stratigraphic sequence

exposed in the trench. These unconformities and weathering intervals provide useful relative age information for constraining the age of the deformation structures.

The oldest erosional event recognized in the trench occurred some time following deposition and local solution subsidence of the Miocene Hawthorn Formation (Unit H). The warped surface of Unit H was eroded to a planar surface of little or no relief. Based on the maximum magnitude of warping described below, this major erosional event must have lowered the land surface in some areas by 15 to 20 feet.

Following erosion, the surface of Unit H was exposed to a long period of weathering and soil development under stable surface conditions. Locally preserved at this surface is a strongly developed relict soil B-horizon up to 3-feet-thick (Fig. 3 and 4). The base of the B-horizon is typically in sharp contact with a deeply weathered, mottled soil C-horizon. The C-horizon extends into Unit H from 5 to 10 or more feet. Even under rapid soil-forming conditions, such a strongly developed soil profile probably required more than 10,000 years to form and may have required in excess of 100,000 years to form.

A second interval of less extensive erosion followed development of the soil and preceeded deposition of the eolian sand of Unit I. The erosion has everywhere removed the soil A-horizon, commonly removed the B-horizon, and channeled into the underlying weathered part of Unit H.

Local preservation of the B-horizon, however, indicates that the erosion was not generally extensive. The most significant erosion occurred at the northwest end of the trench where five-foot-deep channels are cut into Unit H on both walls and most of Unit H has been removed (Fig. 3, Sta. 250 to 280; Fig. 4, Sta. 250 to 280).

Following this erosion, the eolian sand of Unit I was deposited. A second interval of weathering and soil development is evident in the upper part of Unit I at the present topographic surface. The present-day soil has little or no development of soil horizons and probably required less than 10,000 years to form.

Each of these erosional and weathering events occurred during the late Miocene, Pliocene, or Quaternary. Although the time required for each event is not known, the cumulative time is probably on the order of 100,000 to several 100,000 years. This geomorphic and pedologic evidence thus provides reasonably strong relative age criteria for constraining the age of development of the Coastal Plain deformation structures.

An earlier third interval of weathering is also suggested by the strong mottling and presence of clay nodules in Unit G (Table 1). This horizon is separated from the overlying soil developed in Unit H by up to 10 feet of yellow, relatively unweathered sediment (Figure 4, Sta. 650). Weak clay-skins and granular peds are present and the abundant clay in the unit may be, in part, pedogenic. Alternatively, the clay and silt of the

unit may have resulted from primary deposition, and the increase in weathering may reflect perched ground water on Unit G which localized chemical alteration in the unit.

4.0 SMALL-SCALE STRUCTURES

Six types of small-scale structures are exposed in the trench walls. These include contorted or warped bedding, fractures, joints, minor offsets, injected sand dikes of a variety not previously described in the literature, and clastic dikes of the variety previously described by Heron (1965), Siple (1967), Zupan and Abbott (1975), Secor (1980) and many others.

4.1 Contorted Bedding

Coastal Plain sediments exposed in the trench are deformed into a series of broad depressions and arches (Fig. 2, 3 and 4). The folds have an amplitude ranging from 5 feet (Fig. 4, Sta. 410) to more than 20 feet (Fig. 4, Sta. 755) and a wavelength of 50 feet to more than 150 feet (Fig. 5). They influence bedding attitudes in Units A through H; beds of Unit I are not deformed. Beds of Units D and E appear to locally thin over the crests of some arches and thicken into depressions (Fig. 3, Sta. 270 to 350) while beds of Unit F locally thin and pinch-out over the crests of some arches (Fig. 4, Sta. 430 to 520) suggesting that some deformation may be contemporaneous with deposition. The thickening and

thinning of units exposed in the trench, however, is partially artificial, resulting from the changing attitudes of the beds in the trench wall. Facies changes and ground-water iron-oxide alteration also obscure and complicate these thickness relationships.

The warps exposed in the trench walls are not laterally persistent across the trench (Figs. 3 and 4). The number, size, and position of the deformation troughs and crests cannot be correlated from wall to wall indicating that the structures have a complex three-dimensional configuration.

To analyze this configuration, the X, Y, and Z coordinates of 49 surveyed points and bedding attitudes from 40 points were used to contour the deformed surface of Unit F. The trench walls slope from 35 to 45 degrees permitting good three-dimensional reconstruction of the warped surface. Figure 4 is a computer-generated contour reconstruction and mesh reconstruction of the upper surface of Unit F (and Unit E where F is not present) showing the outline of the trench and locations of the data used. Bedding attitudes were used as vectors to extend the contours into the trench walls.

4.1.1 Origin - The contour reconstruction indicates that the Coastal Plain sediments are deformed into a series of broad domes and sharp, circular depressions. There is no lateral persistence of synclinal or anticlinal fold axes or consistency in the size and orientation of the

warps which would be typical of tectonically generated structures. Rather, the domes and depressions appear to be the result of local, irregular subsidence or compaction of the sediment. In the case of Unit F, these depressions appear to be superimposed on an original bedding surface ranging in elevation from 243 to 246 feet. The dome crests are generally conformable at this elevation indicating that they are the remnants of this former original surface and that no vertical uplift has occurred. The Utley Limestone is approximately 40 to 50 feet beneath the depth of the trench and dissolution and removal of material from the Utley, documented during previous VEGP site investigations (Georgia Power Co., 1984), suggests that the deformation of Coastal Plain sediments probably reflects collapse and subsidence of sediment into depleted areas of the Utley Limestone.

4.1.2 Age - The age of sediment collapse is moderately well constrained. Collapse followed and possibly occurred contemparaneously with the late Eocene and Miocene deposition of Units D through H. The collapse does not involve beds of Unit I and is clearly older than the major erosional event which eroded the warped surface of Unit H at least 100,000 and probably more than several 100,000 years ago.

4.2 Fractures, Joints, and Minor Offsets

Associated with the domes and depressions are numerous fractures, joints and small offsets. These structures are most prevalent in Units D, E, F,

G, and H on the limbs of the more strongly warped depressions. They generally die-out downward into the loosely consolidated sands of Units A, B and C and are truncated upward by Unit I. In the upper portions of Unit H, the fractures and offsets typically merge with clastic dikes; in some instances clastic dikes also extend undisplaced across offsets (Fig. 3, Sta. 410).

Fracture orientations indicate that they are intimately related to development of the collapse depressions. Attitudes of 107 fractures and joints were obtained at four independent localities (Fig. 3, Sta. 400 to 440 and Sta. 500 to 550, Fig. 4, Sta. 300 to 350 and Sta. 380 to 440). The fractures are primarily vertical with trends ranging from east-west to northeast-southwest. Trend groupings are locally consistent at each locality but the trends vary strongly from warp to warp suggesting a local control for fracture development, probably related to collapse of the depressions.

Numerous small offsets with displacements ranging from 1 to 24 inches are also evident in the trench walls. The larger of these are shown on Figures 3 and 4. Most of the offsets have normal displacement toward or into depressions (Fig. 6); minor reverse displacements also occur near the crest of some arches. None of these offsets extend across the trench. Offsets with orientations trending across the trench cannot be traced laterally from wall to wall.

Attitudes of 46 offsets were recorded at eight separate localities of the trench (Fig. 3, Sta. 300 to 400, 450 to 500, 500 to 600, 680 to 750, and 750 to 850; Fig. 4, Sta. 550 to 600, 700 to 750, and 750 to 830). Offset plane orientations range from steeply dipping to flat-lying with trends of east-west, northwest, north-south, and northeast. The orientations are locally consistent on the limbs of individual arches and depressions but vary strongly from fold to fold. Multiple attitudes taken on some offsets indicate that the offset orientations vary up-section and in some instances actually arc over the centers of some depressions (Fig. 7).

Many offsets splay both up-section and down-section. Up-section these splays are coincident with large zones of "clastic dike" development in the upper weathered part of Unit H (Figs. 7 and 8). Down-section, the offsets show decreasing displacement into the loosely consolidated sands of Units A, B, and C.

4.1.2 Origin - These several observations indicate that the offsets are local phenomena. They are spatially related to depressions and have resulted from sediment collapse, differential subsidence and brittle block failure of overlying semi-consolidated sediment. The offsets are not laterally or vertically continuous or consistently oriented regionally; thus they are not tectonically capable structures.

4.2.2 Age - Age of the fractures and offsets is poorly constrained. They are younger than the Eocene and Miocene deposits of Units A through

H but older than the late Pleistocene or Holocene sand of Unit I. In addition, they typically merge with or are cut by clastic dikes and they are truncated by the erosional events and soil development which preceeded deposition of Unit I. These relations suggest that the offsets are at least 100,000 and probably more than several 100,000 years old.

4.3 Clastic Dikes

Clastic dikes are well exposed along the length of the trench. They occur predominantly in the upper, near-surface, weathered part of Unit H and have the following characteristics:

1. The dikes generally merge upward into the deeply weathered soil B-horizon at the surface of Unit H (Fig. 4, Sta. 180 to 250; Fig. 9) or, where this weathered horizon has been removed by erosion, the dikes are abruptly truncated and overlain by younger sediment of Unit I.

2. The dikes range from 1 mm to greater than 20 cm across. averaging 2 to 3 cm across. The better developed dikes contain a central core of dark grayish green to white clay up to 5 cm thick (Fig. 9). The clay is concentrically bordered by a zone of bleached clayey sand which, in turn, is bordered by a zone of iron-oxide cementation or enrichment.

3. The dikes are best developed over areas of maximum warping and fracturing; they are less developed in areas where warping and fracturing of lower beds is minimal. Many dikes are coincident with or cluster around fractures and offsets where these structures enter the weathered portion of Unit H (Fig. 3, Sta. 340 to 390, Sta. 450 to 480; Fig. 4, Sta. 580, Figs. 7 and 8).

4. Laboratory analyses indicate that the dikes represent slight weathering of feldspar and clay accumulation relative to the host sediment. Grain size analyses indicate that the clayey sand zone is texturally slightly enriched in clay and silt over the host sediment. X-ray diffraction analyses indicate that the central clay core is predominantly kaolinite with minor amounts of chlorite and illite, and that the clayey sand is predominantly quartz with minor kaolinite, and is depleted in feldspar compared to the host sediment.

5. The dikes in virtually all cases are associated with mottling and clay nodules in the weathered portion of Unit H. The clay nodules are texturally similar to the clay in the dikes, although compositional similarity has not been determined.

6. The dikes and associated mottling decrease downward in density and size. In most cases, the dikes taper downward and pinch-out over a 5-to 15-foot interval (Fig. 4, Sta. 180 to 250, Sta. 580;

Fig. 9). Occassionally, however, a dike extends over 20 feet, through Unit H and into underlying units (Fig. 8). These dikes in all instances merge with fractures or offsets which continue at depth below the lower extent of the dike (Fig. 3, Sta. 340 to 390; Fig. 8).

7. In the upper part of Unit H, many dikes also extend undisplaced across offsets (Fig. 3, Sta. 400 to 410) indicating that development of these dikes post-dates development of the offsets.

8. The orientations of 104 dikes were recorded at three locations of the trench (Fig. 3, Sta. 200 to 240; Fig. 4, Sta. 180 to 250; Sta. 300 to 310). Similar to the orientations of fractures and offsets described earlier, the orientations of the dikes are locally consistent on the limbs of individual depressions or arches but vary greatly from fold to fold. The dikes typically are vertical with principal average trends at the three localities of approximatey N45E, N5W, and N60E, respectively.

Dike orientations at Sta. 180 to 250 (Fig. 4) are particularly significant for assessing the origin of the fractures in which the dikes formed. These dikes are extremely well developed, spaced 1 to 2 feet apart (Fig. 9), and occur over a 70 foot distance across the center of a major depression. Based on 56 attitudes, the dikes show a progressive variation or rotation in strike across the depression from N20E to N35W.

At Sta. 180 to 200, multiple attitudes on the same dikes indicate that the dikes are near vertical, arcuate structures. The progressive rotation in strike, arcuate shape, and spatial association with a depression strongly indicates a genetic relationship of fracturing and subsequent clastic-dike development with growth of the depression.

4.3.1 Origin - As described by Heron and others (1971, p. 1801), the origin or development of clastic dikes involves three separate but interrelated problems: (1) origin of the fractures; (2) source of the clastic material; and (3) method of emplacement of the dike materials. The field relations described above indicate strongly that the clastic dikes result from weathering and soil-forming processes preferentially enhanced along local, pre-existing fractures, joints, and offsets. As described earlier, the fractures and offsets probably resulted from tensional collapse during subsidence and development of depressions in Coastal Plain sediments. There is no evidence in the trench to indicate concurrent fracturing with dike development due to stresses imposed by volume readjustments resulting from either soil weathering (as described by Johnson and Heron, 1971) or by soil dessication.

4.3.1 Regional Character - To further evaluate: (1) the source(s) of clastic material; (2) alternative methods of emplacement (e.g. liquefaction or infilling from above); and (3) the role of ground water in their development, exposures of clastic dikes in an area within 25 miles of the trench were examined to assess their regional occurrence and

character. These studies indicate that clastic dikes in the area have the following common characteristics, in addition to those observed at the trench site:

1. The dikes are widely distributed through the region in deeply weathered clayey and silty sands of the Hawthorn and Barnwell Formations.

2. The dikes occur in nearly all exposures of the weathered profile but are rare in exposures of stratigraphically lower, less weathered sediment.

3. The dikes are typically near vertical features with consistent local trends at three large exposures of N55E, N15W, and N5E, respectively.

4. The dikes contain a central zone of bleached host rock bounded by a cemented zone of iron oxide. Some dikes contain a clay core.

5. Grain size analyses on samples from three localities indicate that the dike interval contains the same grain size distribution as the host sediment with slightly more silt and clay (excluding the clay core).

6. Pebble interbeds in the Hawthorn and Barnwell in several instances continue across and are contained within the clastic dike without evidence of vertical displacement or upward or downward movement of pebbles in the dike.

7. The dikes and associated mottling are clearly associated with changes in sedimentary facies. In some cases, the dikes and mottling abruptly die-out with depth at an impermeable and unruptured clay bed which apparently served as a barrier to ground-water migration. In other cases, the dikes become less frequent and die-out laterally as the host-rock matrix changed from a tight sandy clay to a less consolidated coarse sand and gravel. Permeability apparently changed from fracture permeability in the sandy clay to porous permeability in the coarse sand and gravel.

8. Ground-water migration along the dike is strongly indicated by common "pipe" structures within the dike. The pipes pinch and swell and are lined by cemented iron-oxide.

9. Geochemical reaction with ground water is indicated by concentric zonation in the host rock of iron-oxide accumulation around the dike. An interference pattern of this zonation commonly occurs where dikes cross one another.

0119g

10. The clastic dikes appear to perpetuate fracture permeability through a positive-feedback mechanism as the dike develops. Shrink and swell of the clay in the core of the dike maintains an open fracture along the length of the dike. The open fracture enhances ground water migration, weathering, and accumulation of additional clay which, in turn, shrinks and swells. These open fractures are present today along many clastic dikes extending to several feet below the surface.

11. Infrequently, some dikes are laterally and vertically discontinuous and form an "en echelon" pattern suggestive of tensional stress fractures.

12. At several locations, clastic dikes are developed along small offsets; at others, the clastic dikes are displaced by small reverse faults.

13. Regardless of the origin of fractures, joints and offsets, clastic dikes appear to develop if the proper conditions of weathering occur.

4.3.3 Regional Origin - The field relations and laboratory data from the trench and surrounding area indicate that the source of clastic material is largely weathered in-situ host sediment supplemented by downward and lateral translocation of clay products by ground water and

pedogenic processes. There is no evidence of liquefaction and fluid injection or of clastic infilling from above: (1) There is no lower or upper primary source for the clay or clayey sand contained in the dike; (2) The "en echelon" pattern and continuation of primary sedimentary bedding across and within the dikes are difficult to reconcile with injection or infilling of material; and (3) the dikes do not exhibit the characteristics of liquefaction conduits described by Cox and Talwani (1984) and Cox (1984) in the Pleistocene sediments near Charleston, S. C. (The liquefaction dike conduits were highly variable in orientation and thickness and rapidly flared toward the surface into an inverted cone shape). In addition, many characteristics of the dikes (e.g., chemical zonation, piping structures, clay weathering and accumulation) require an extended period of time to develop and are not the result of relatively instantaneous events such as faulting, liquefaction, or sediment infilling. In a sense, to define these features as "clastic dikes" is a misnomer in terms of their origin. The term, however, has attained common usage in current literature of Coastal Plain geology and is thus retained in this paper as a descriptive term for these features.

4.3.4 Age - The age of the dikes exposed in the trench is poorly constrained. They are younger than the parent Eocene to Miocene deposits of Units A through H (Barnwell Group and Hawthorn Formation) and younger than sediment collapse which produced the fractures and offsets along which many dikes developed. They probably developed during the major weathering event which produced the relict paleosol on Unit H and are

thus older than the middle to late Pleistocene erosion of the Unit H paleosol and subsequent deposition of the late Pleistocene and Holocene eolian sand of Unit I.

4.4 Sand Dikes

Sand dikes occur at three localities in the trench (Fig. 3, Sta. 570 to 590, Sta. 642, Sta. 830). The locality at Sta. 570 to 590 contains a large complex of sand dikes exceeding 20 feet in length. The latter two localities contain single, laterally discontinuous, thin dikes. The dikes consist of lavender, loosely consolidated, well sorted, very fine, clean quartz sand and are everywhere contained within Unit D.

Orientation of the dikes varies greatly. At each locality, they dip steeply down the limbs of large depressions and flatten upward toward the crests of arches (Fig. 3, Sta. 570 to 590). Near their upward terminus, the dikes locally flare upward or sag downward (Fig. 3, Sta. 585 to 588). They locally intersect but do not penetrate Unit E; rather they migrate up-dip along the contact (Fig. 3, Sta. 575). Downward, toward the trough of the depression, the dikes thin, become irregular, and are difficult to distinguish as they enter Unit C.

The sand dikes locally control the rate and direction of ground water flow. The dikes interupt ground water iron-oxide laminae and liesagang rings within Unit D and locally produce zones of iron oxidation which

transect Unit D (Fig. 3, Sta. 570). In addition, thin bands of white kaolinite clay concentrated by ground water in the host sediment concentrically border portions of some dikes (Fig. 3, Sta. 575).

4.4.1 Origin - The dikes probably originated by fluid or plastic injection. The dikes have an apparent lower parent source in the fine sand beds of Unit C. Although a direct connection of the dikes with Unit C was not observed, the fine sand of Unit C is nearly identical to the fine sand of the dikes: loosely consolidated, well sorted, clean, and predominantly composed of quartz. Close spatial association with limbs of major depressions suggests that the liquid injection resulted from development of the depression. Hypothetically, a sudden increase in overburden pressure during high water table conditions in response to subsidence and sediment collapse may have locally mobilized the loosely consolidated sand of Unit C and possibly of Unit B. Plastic or fluid migration of the sand up-section probably occurred along previously developed or concurrently developing fractures in the overlying brittlely deforming sediment.

4.4.2 Age - Age of the sand dikes is moderately constrained. They are younger than Units D and E and, if the dikes originated during sediment collapse as postulated above, they must also post-date Unit H because this unit is involved in the collapse. The dikes, however, are older than a subsequent period of sediment collapse which produced minor displacement of the dikes along offsets (Fig. 3, Sta. 580). The offsets,

in turn, localized clastic dike development during paleosol weathering of Unit H prior to erosion of Unit H in the Pleistocene and deposition of the eolian sand of Unit I.

5.0 SUMMARY

Coastal Plain small-scale structures evident in the VEGP trench are interpreted to be local phenomena related to dissolution of an underlying carbonate bed, the Utley Limestone, followed by one or more phases of plastic and brittle collapse of overlying sediments. They are not tectonic features nor are they indicative of regionally significant seismic activity.

Collapse of sediment over the disolving limestone created depressions in the Eocene and Miocene Coastal Plain strata. Fractures and joints are spatially associated with the depressions and resulted from brittle, tensional failure of consolidated and semi-consolidated sediment. Displacement along many fractures resulted from irregular differential settlement of blocks. Most of these displacements are normal into the subsiding depression and many fractures and offsets arc continuously over the center of depressions. The offsets are local in extent and small. No offset extends across both walls of the trench.

Sand dikes resulted from plastic or liquid injection of loosely consolidated fine sand into the overlying, fractured, relatively

consolidated sediment. The dikes dip steeply down the limbs of depressions and probably mobilized in response to increased overburden pressure during the early phase of sediment collapse. Fracturing and faulting during subsequent phases of collapse locally cut and displace the sand dikes. Clastic dikes resulted primarily from weathering and soil-forming processes preferentially enhanced along pre-existing fractures and faults. Their present geographic distribution is controlled by the depth of weathering and paleosol development in the Hawthorn and Barnwell sediments and by subsequent erosion of the land surface. Major dike trends at three localities in the trench, three localities in the surrounding area, and at localities reported by Secor (1980), Heron (1971), and Zupan and Abbott (1975) vary widely supporting a local control for their development as opposed to a regional tectonic control.

The chronologic sequence of events leading to development of the small-scale deformation structures includes:

1. Deposition of the Cretaceous to Miocene Coastal Plain sediments.

2. Partial dissolution of the Utley Limestone.

3. Subsidence, collapse and irregular, differential settlement of the Barnwell and Hawthorn strata probably in a sequence of phases. Local thickening of beds into depressions suggests that dissolution and collapse may have begun during sediment deposition in the late Eocene or Miocene.

4. Plastic or liquid injection of sand dikes during an early phase of sediment collapse.

5. Fracturing, jointing, and offsetting of strata concurrent with sand-dike emplacement and during later phases of sediment collapse and differential subsidence.

6. Major episode of erosion which lowered the deformed surface of the Coastal Plain sediments to a relatively planar surface.

7. Development of clastic dikes during a major period of deep surface weathering and soil development.

8. Local erosion and channeling into the weathered Coastal Plain surface.

9. Deposition of eolian sand during the late Pleistocene or Holocene.

10. Holocene surface weathering and weak soil development.

6.0 REFERENCES

Cox, J., and Talwani, P., "Discovery of a Paleoliquefaction Site Near Charleston, S.C.", Geological Society of America, Abstracts with Programs, v. 16, No. 3, pp 130, 1984.

Cox, J., "Paleoseismology Studies in South Carolina", University of South Carolina, Master Thesis, 1984.

Georgia Power Co., "Alvin W. Vogtle Units 1 and 2, Final Safety Analysis Report", Appendix 2B, Section 2.5, 1984.

Heron, S. D., Jr., Johnson, H.S., Jr., and Pooser, W. K., "Clastic dikes in the western Coastal Plain of South Carolina", Geological Society of America Special Paper 87, 1966.

Heron, S. D., Jr., Judd, J. B., and Johnson, H.S., Jr., Clastic Dikes Associated with Soil Horizons in the North and South Carolina Coastal Plain" Geological Society of America Bulletin, v 82, pp 1801-1810, 1971.

Howell, D. E., and Zupan, A. W., "Evidence for Post-Cretaceous Tectonic Activity in the Westfield Creek Area North of Cheraw, South Carolina", South Carolina State Development Board, Division of Geology, Geological Notes, v 18, no. 4, pp 98-105, 1975.

Inden, R. F., and Zupan, A.J.W., "Normal Faulting of Upper Coastal Plain Sediments, Ideal Kaolin Mine, Langley, South Carolina", South Carolina State Development Board Division of Geology, Geological Notes, v 19, pp 159-165, 1975.

Johnson, H.S., Jr. and Heron, S.D., Jr., "Slump features in the McBean Formation and younger beds, Riley Cut, Calhoun County, South Carolina", South Carolina State Development Board, Division of Geology, Geol. Notes, v. 9, no. 3, p. 37-44, 1965.

McDowell, R. C., and Houser, B.B., Map Showing Distribution of Small-Scale Deformation Structures in a part of the Upper Coastal Plain of South Carolina and Adjacent Georgia", U.S. Geological Survey Miscellaneous Field Studies Map MF-1538, 1983.

Secor, D.T., "Geological Investigation at the Chem-Nuclear Waste Storage Site, Barnwell, South Carolina, February 24, 1980." Allied-General Nuclear Services.

Seeber, L., and Armbruster, J.G., "The 1886 Charleston, South Carolina Earthquake and the Appalachian Detachment," Journal of Geophysical Research, v 86, no. B9, pp 7874-7894, 1981.

Siple, G.E., "Geology and ground water of the Savannah River Plant and Vicinity, South Carolina", U.S. Geological Survey Water Supply Paper 1841, p. 57-60, 1967.

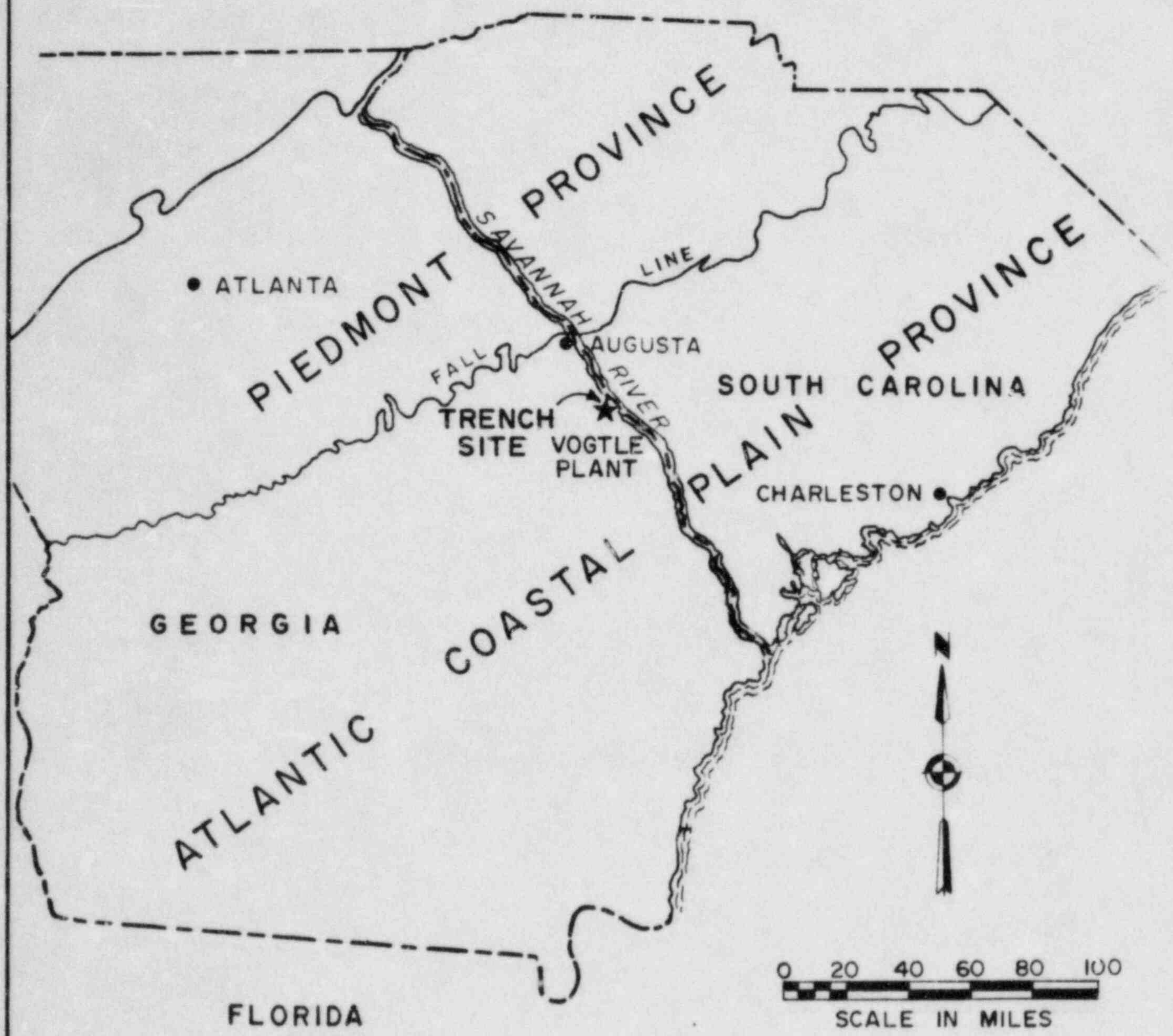
Zupan, A.J.W., and Abbott, W.H., "Clastic Dikes" Evidence for Post-Eocene (?) Tectonics in the Upper Coastal Plain of South Carolina", South Carolina State Development Board, Division of Geology, v 19, pp 14-23, 1975.

Tables

Table 1: Informal Stratigraphic Units Exposed in Trench Wall

Unit	Thickness (ft)	Lithology
I	5 to 20	White, gray and tan, well sorted, loosely consolidated, fine quartz sand. Locally cross-bedded and unconformably overlies Unit H.
H	5 to 30	Yellow grading upward to red, moderately to poorly consolidated, sorted, sandy clay and clayey sand. Gray and white clay mottles and clastic dikes locally common near upper contact decreasing in density down section. Strongly developed relict B-horizon locally preserved in upper part of unit at contact with Unit I.
G	1 to 3	Red, consolidated clay, silty clay, and clayey silt. Many large, prominent mottles of white clay nodules.
F	1 to 2	Moderately consolidated, laminated, red and yellow, moderately sorted silty fine sand.
E	1 to 2	Weakly consolidated, moderately to well sorted, red, fine sand. Thin layers of consolidated silt and clay locally present in lower part of unit.
D_1	1 to 4	Locally overlies Unit D and is bright yellow, moderately sorted silt and fine sand.
D	4 to 7	Light to dark yellow, moderately consolidated, poorly sorted fine to coarse sand; generally bioturbated, locally mottled white with weathered shell or clay material.
C	4 to 6	Poorly consolidated, grayish-white, mottled red and purple, moderately to well sorted fine to medium quartz sand.
B	2 to 4	Yellowish-tan, moderately consolidated, moderately to well sorted sorted, fine quartz sand.
A	1 to 4	Loosely consolidated, gray to yellow, poorly sorted coarse sand with sparse pebbles.
A_1	0.5 to 2	Lense of tight, grayish tan, clayey silt everywhere contained within Unit A.

Figures



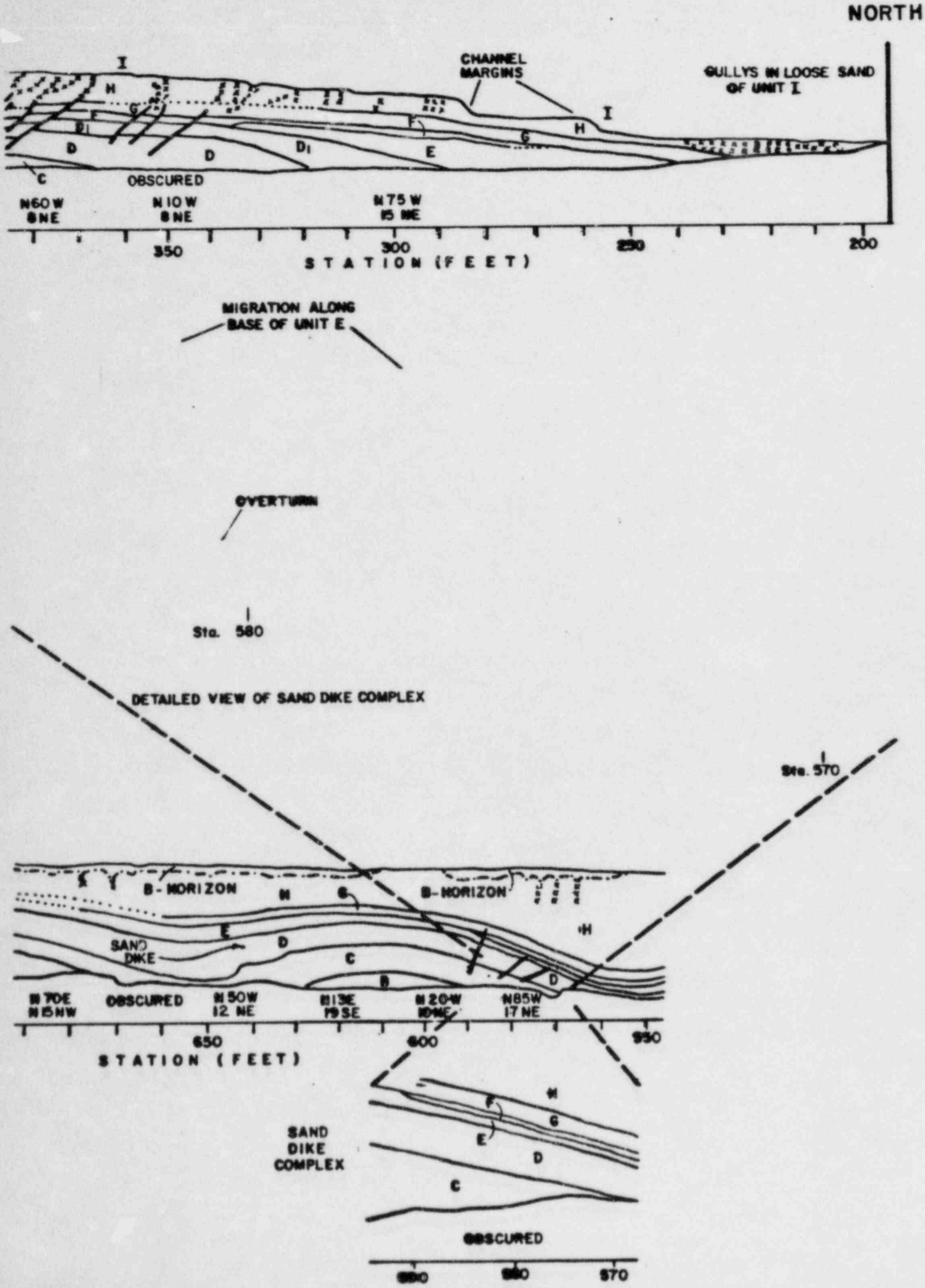
BECHTEL

VOGTLE ELECTRIC GENERATING PLANT
TRENCH STUDY

INDEX MAP

FIGURE 1

Figure 2 — Longitudinal view of west trench wall showing magnitude of contorted bedding.


NORTH
CHANNEL MARGINS
GULLYS IN LOOSE SAND OF UNIT I
I
H
G
F
D1
D
E
C
OBSCURED
N60W 8NE
N10W 8NE
N75W 15 NE
350
300
250
200
STATION (FEET)
MIGRATION ALONG BASE OF UNIT E
OVERTURN
Sta. 580
DETAILED VIEW OF SAND DIKE COMPLEX
Sta. 570
B-HORIZON
SAND DIKE
B
N70E N15NW
OBSCURED
N50W 12 NE
N13E 19SE
N20W 10NE
N85W 17NE
650
600
STATION (FEET)
SAND DIKE COMPLEX
570

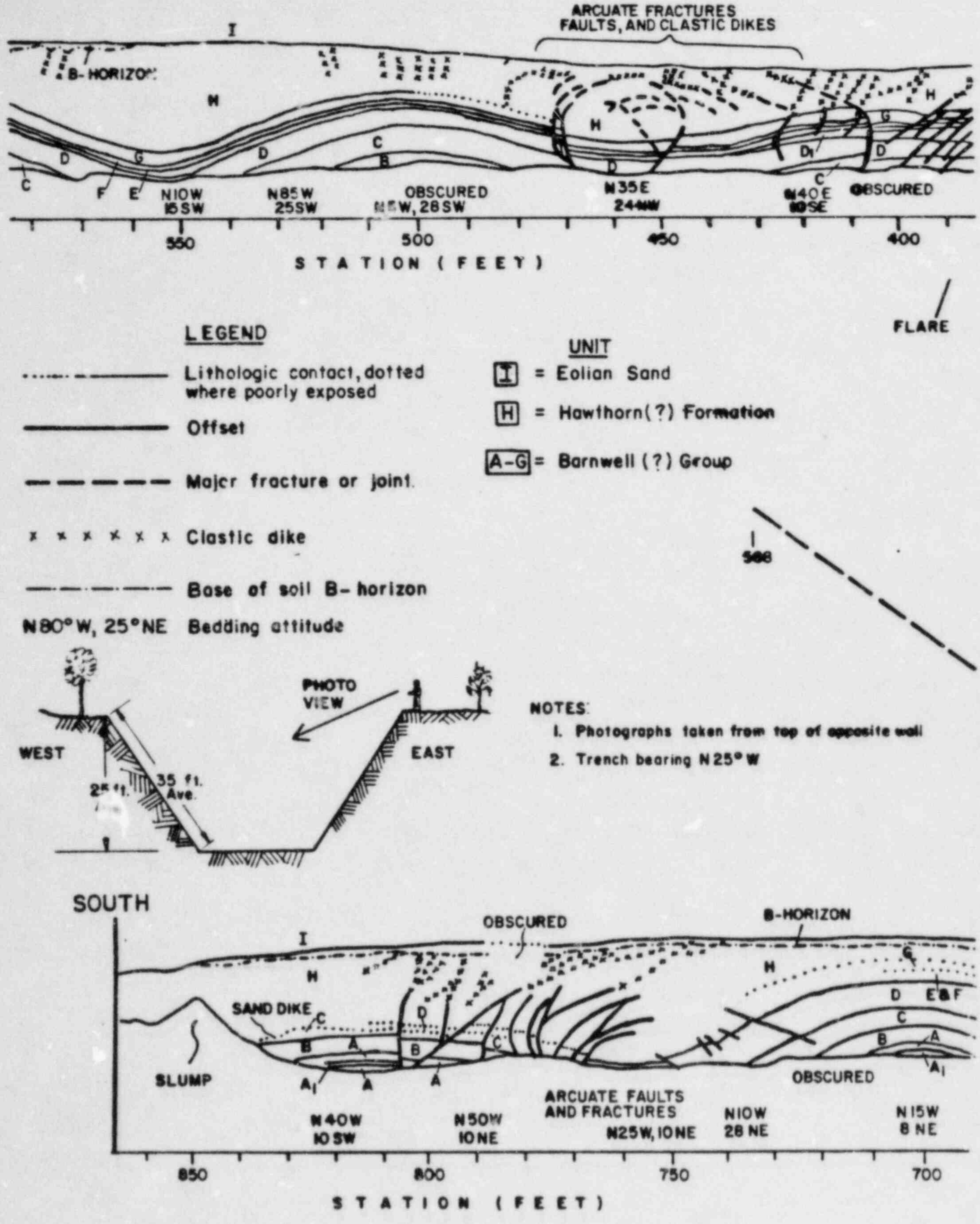
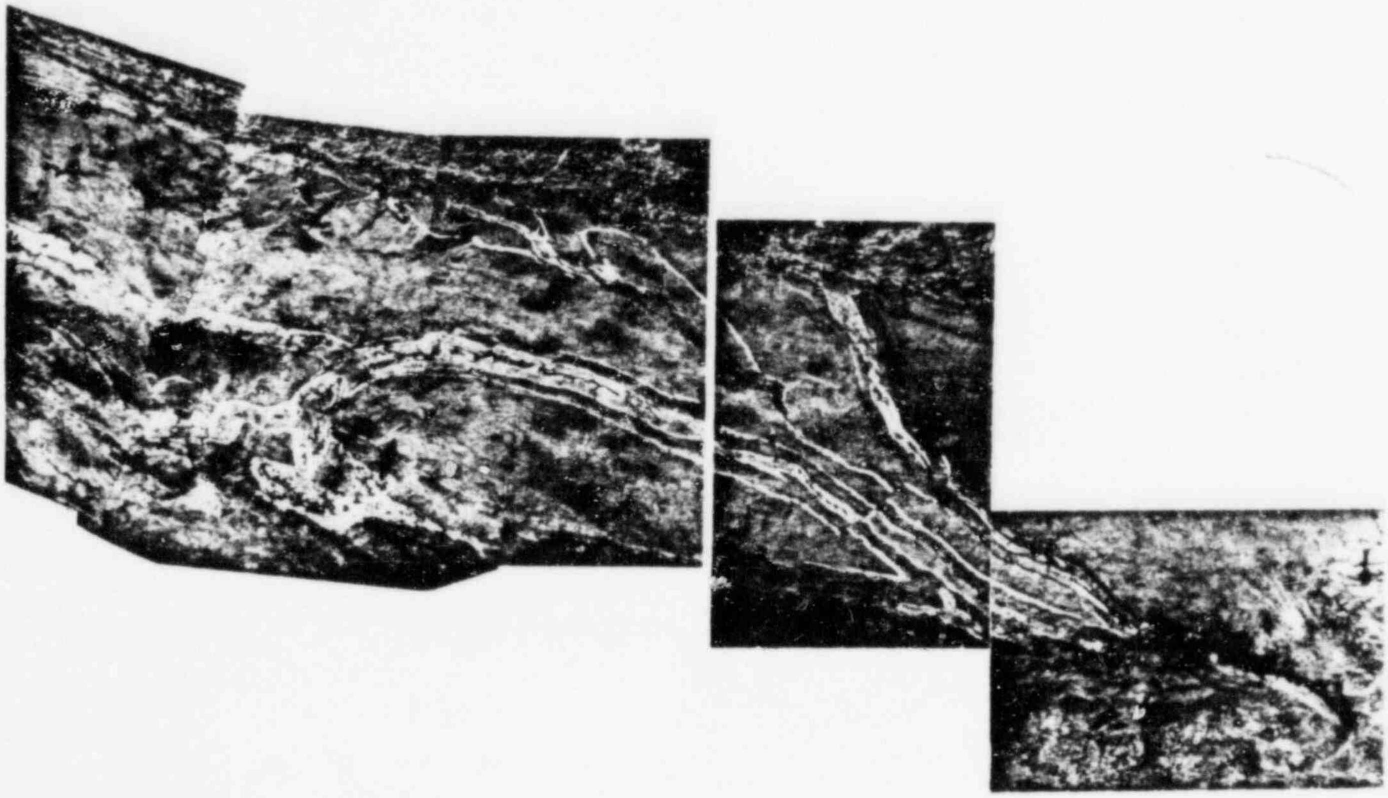
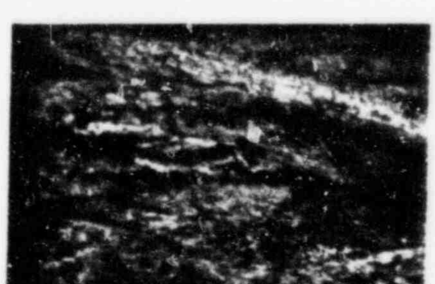
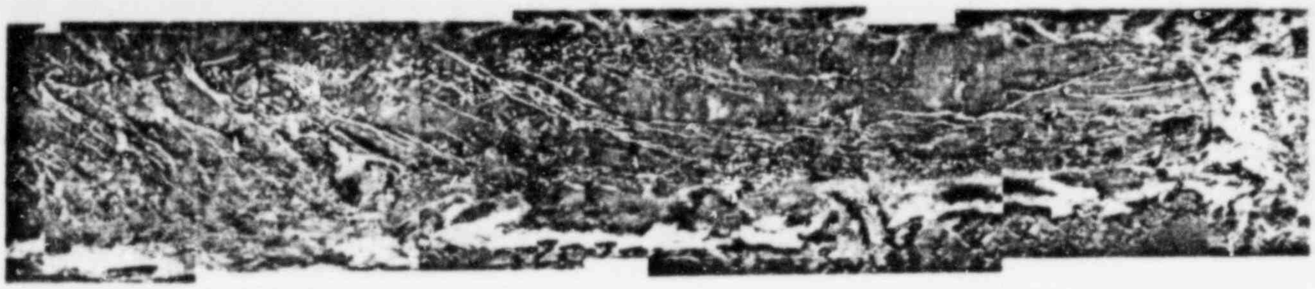
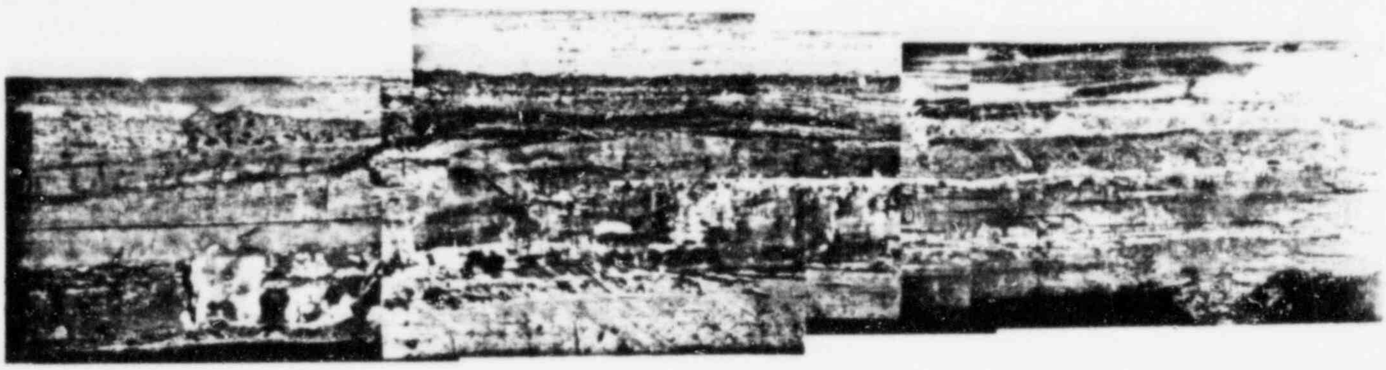


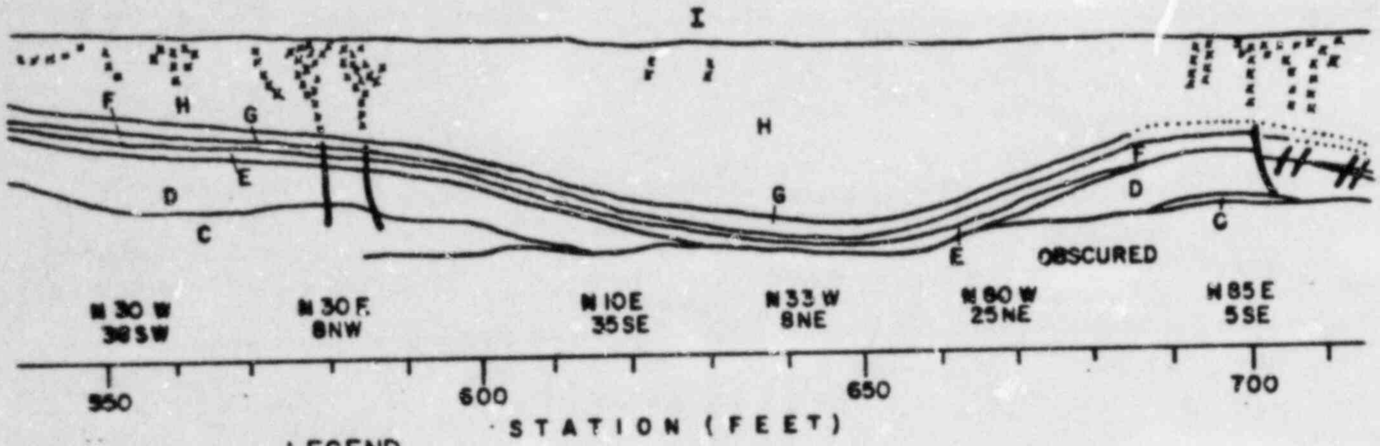
FIGURE 3 - PHOTO-MOSAIC AND GEOLOGIC INTERPRETATION OF TRENCH, WEST WALL.











LEGEND

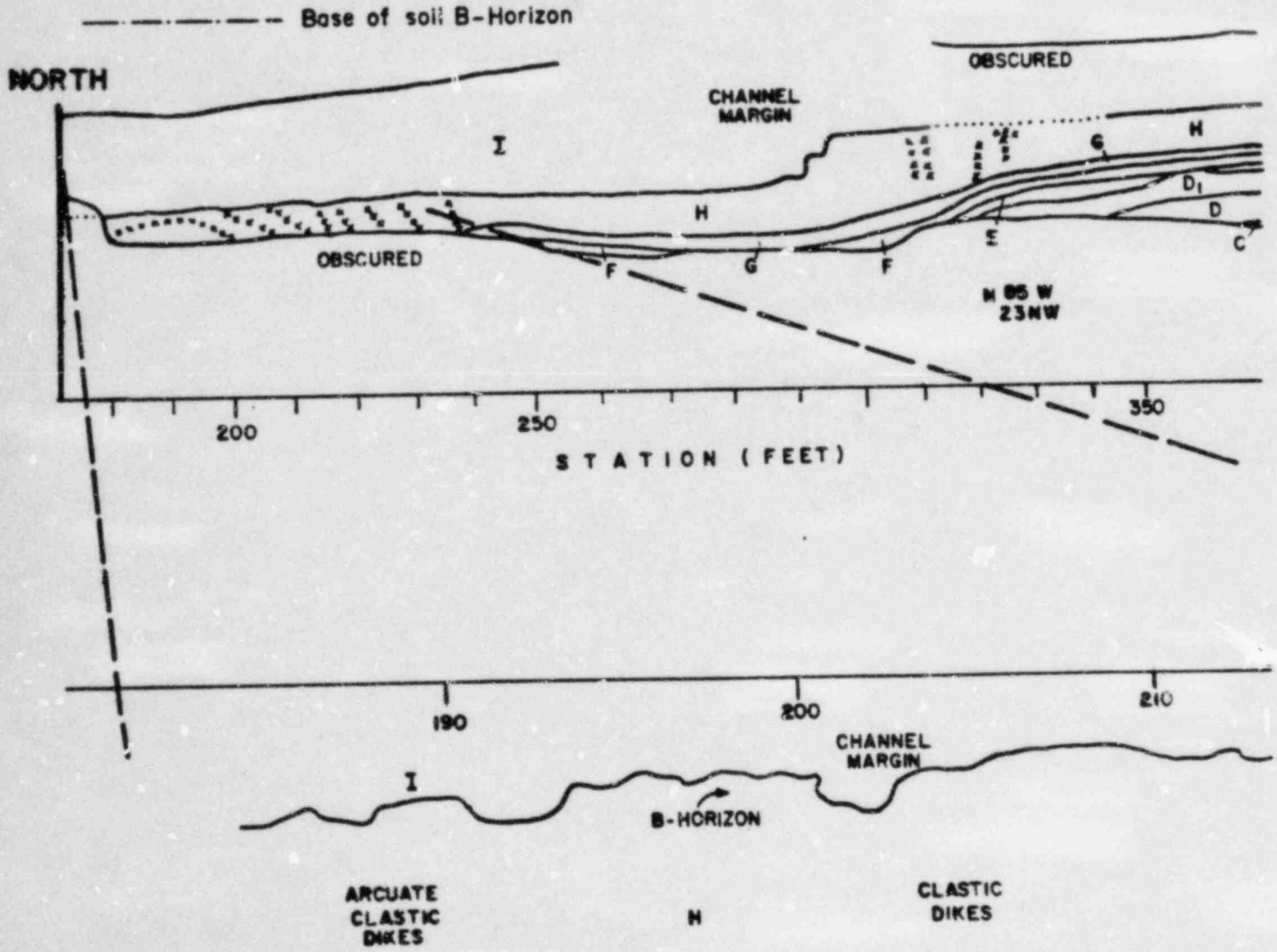
N 80° W, 25° NE	Bedding attitude
············ ——————	Lithologic contact, dotted where poorly exposed
——————	Offset
— — — — —	Major fracture or joint
x x x x x x	Clastic dike
—·—·—·—	Base of soil B-Horizon

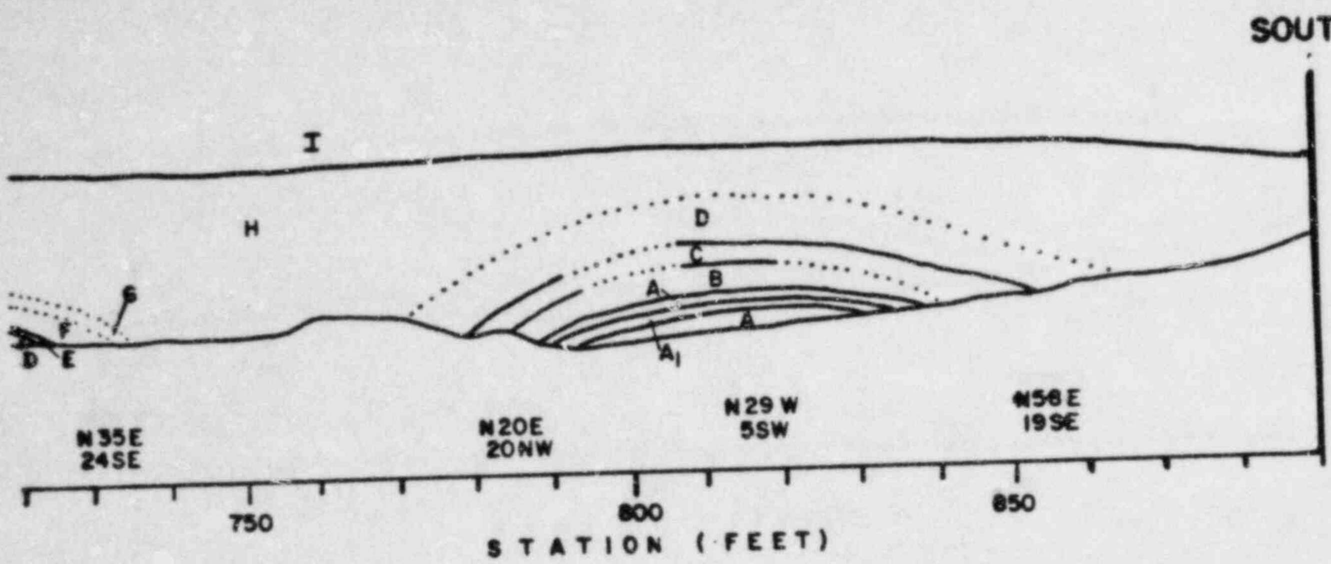
UNIT

I = Eolian Sand

H = Hawthorn (?) Formation

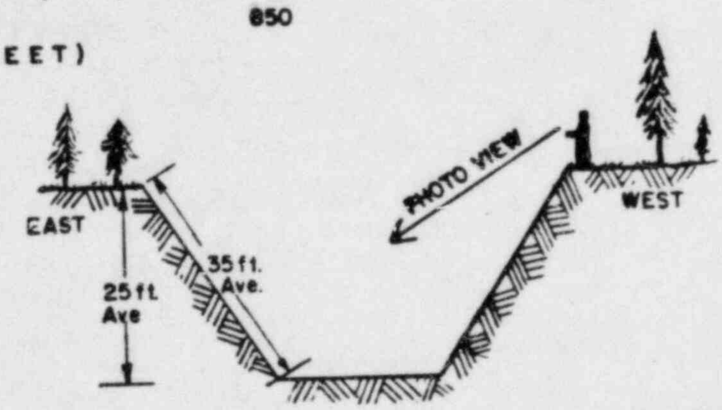
A-G = Barnwell (?) Group





NOTES:

1. Photographs taken from top of opposite wall
2. Trench bearing N 25° W



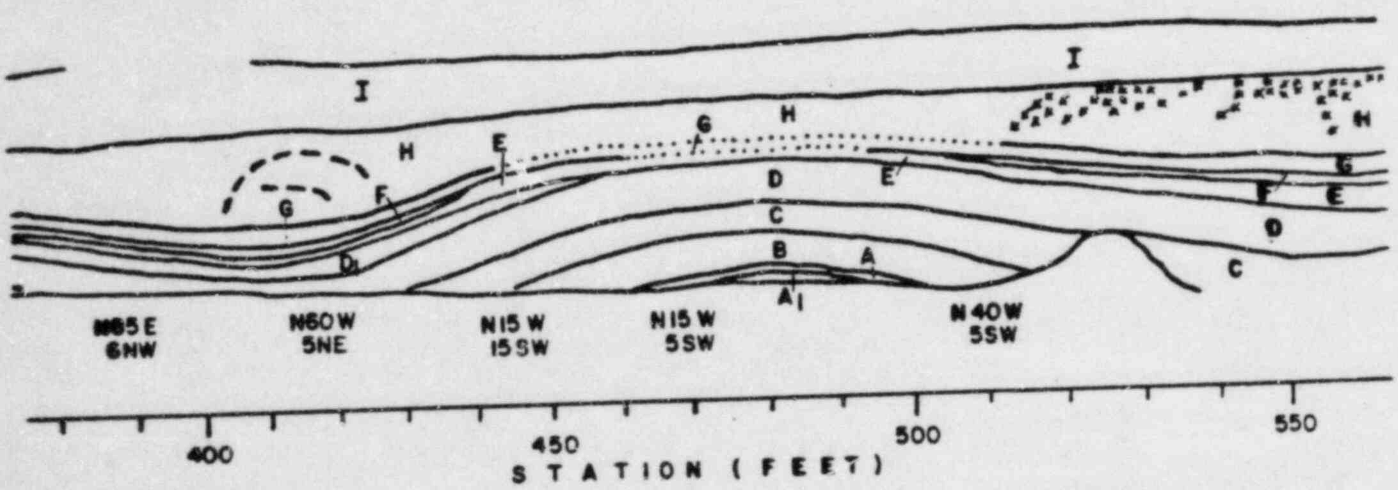
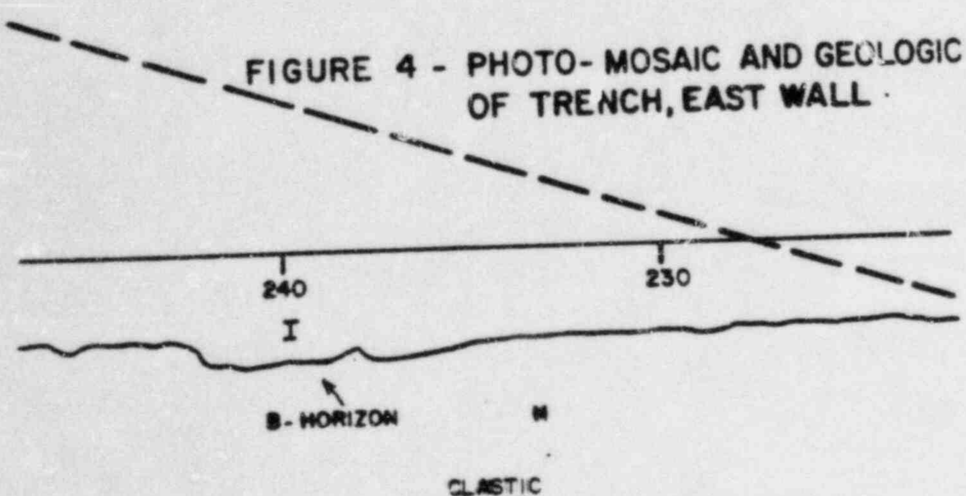
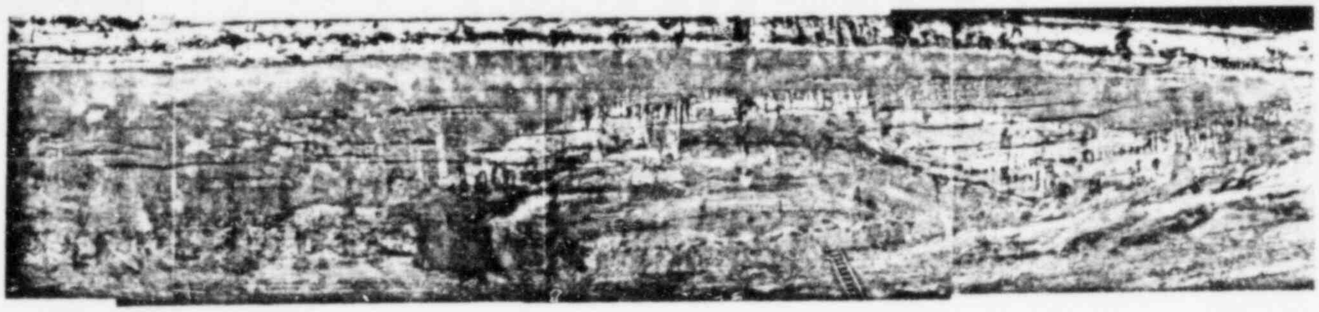
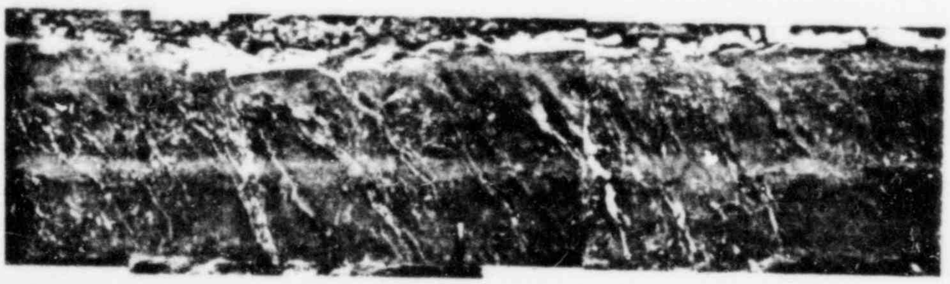
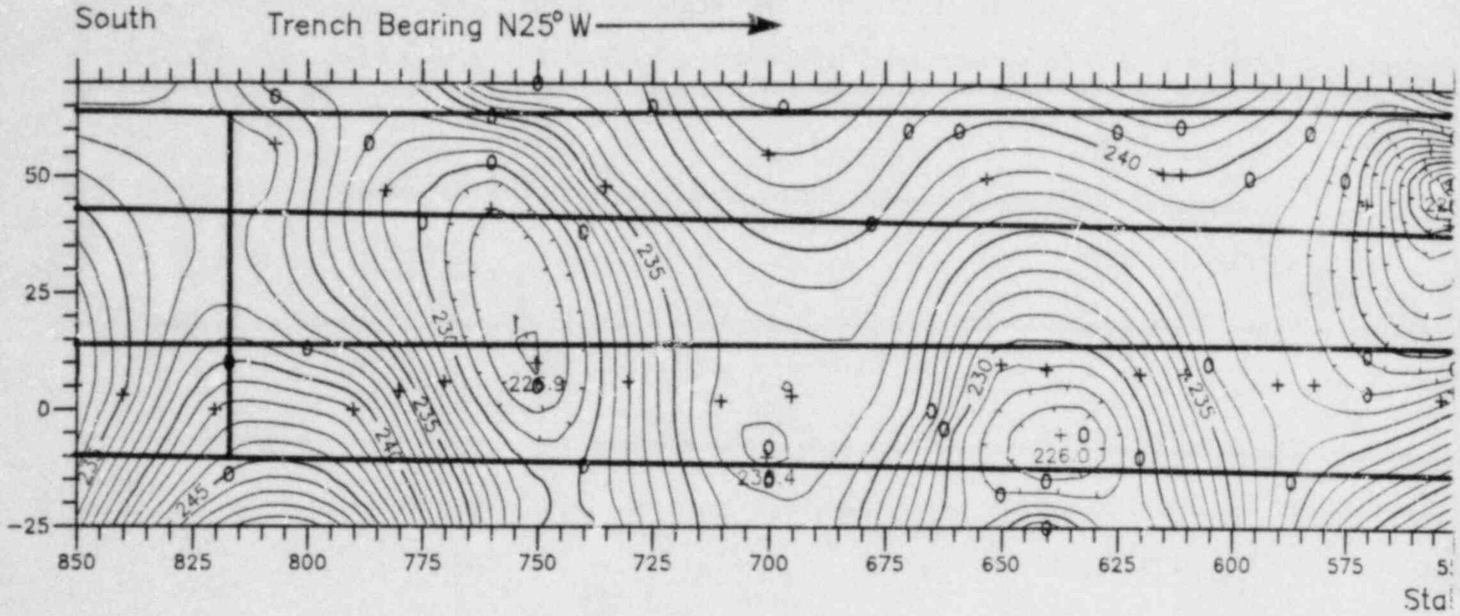


FIGURE 4 - PHOTO-MOSAIC AND GEOLOGIC INTERPRETATION OF TRENCH, EAST WALL

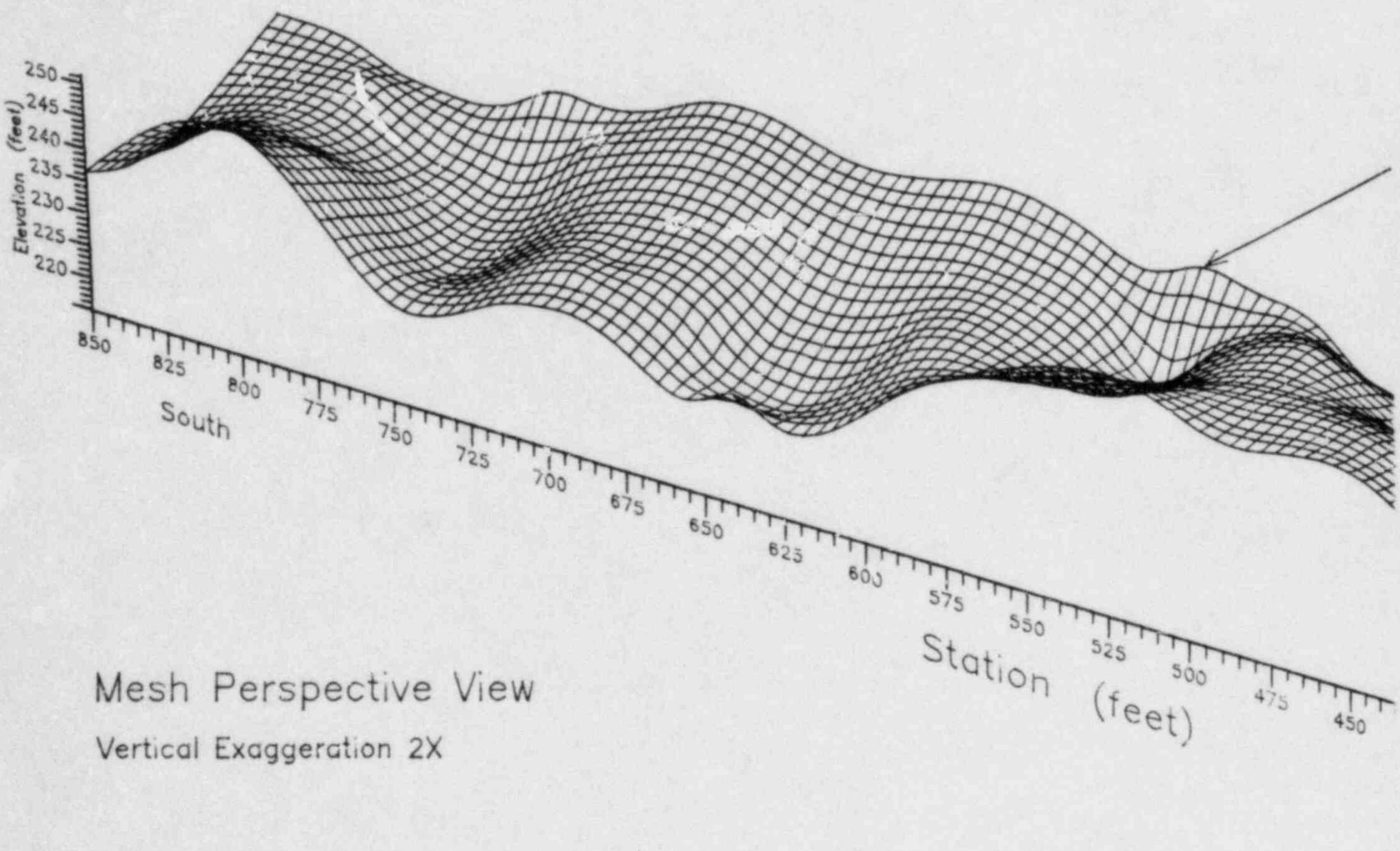






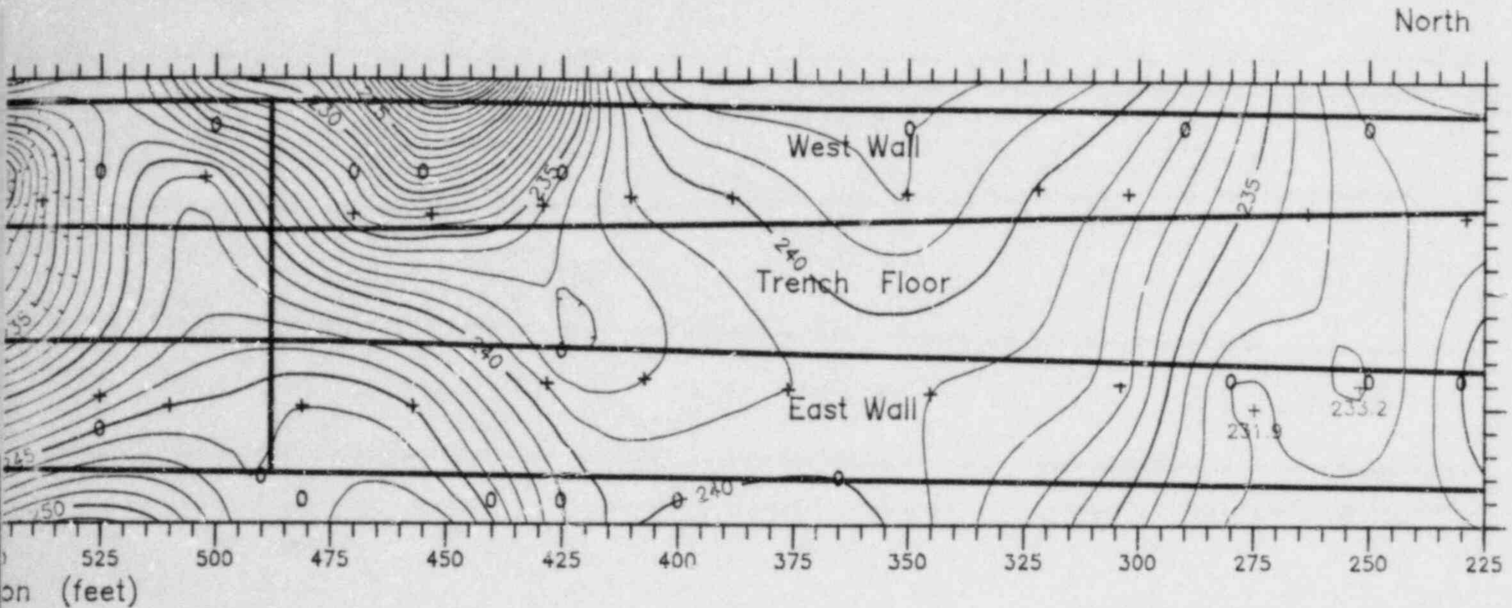


Structure Contour Map, Surface of Unit F – Trench Plan View



Mesh Perspective View

Vertical Exaggeration 2X



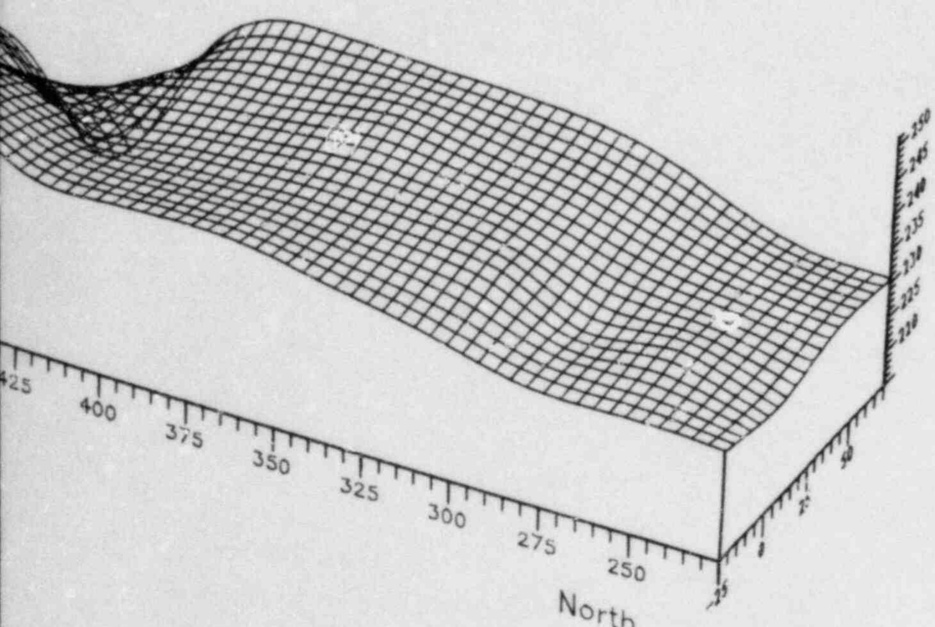
Surface of Unit F

Explanation

+ Surveyed Elevation

0 Elevation Extrapolated From Bedding Attitude

Contour Interval 1 Foot



BECHTEL SAN FRANCISCO	
Vogtle Electric Generating Plant Trench Study	
Surface Geometry of Unit F	
JOB NO.	DRAWING NO.
9510	Figure 5

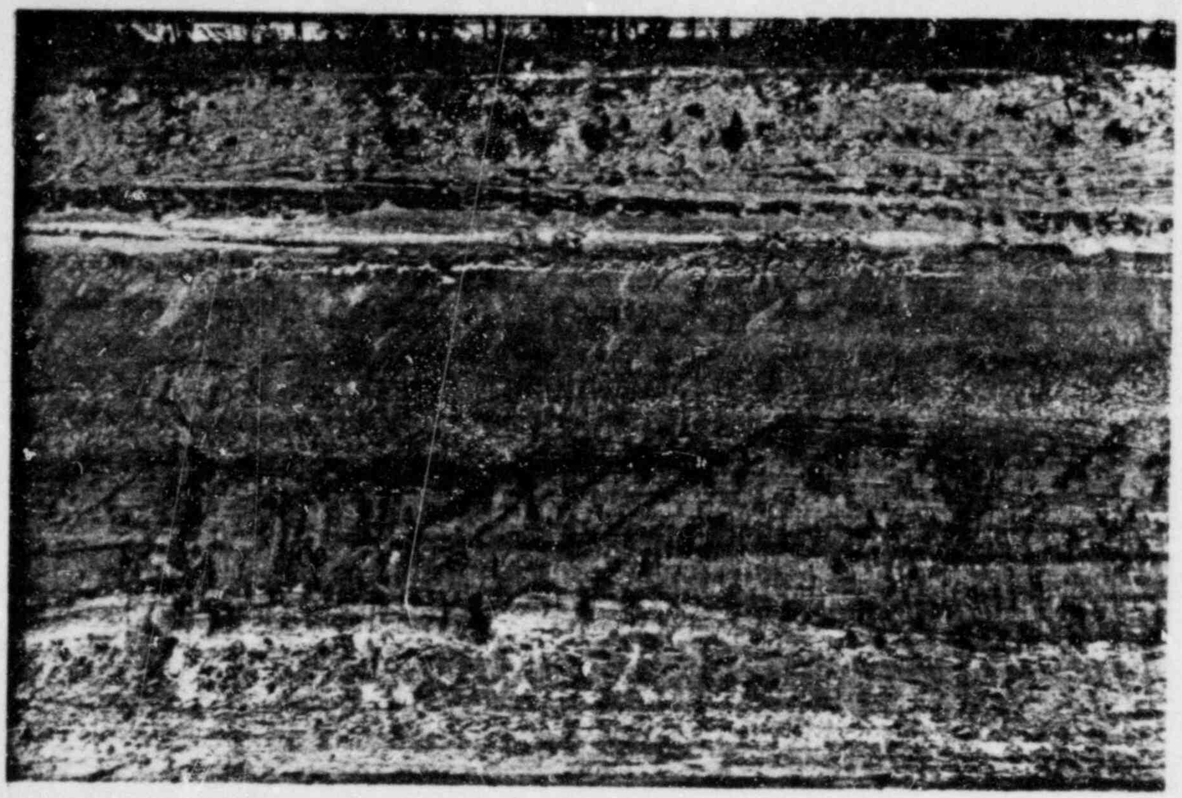


Figure 6 — Small offsets with displacements ranging from 1 to 24 inches; west wall — Station 360 to 410. Offsets typically have normal displacement toward depressions.

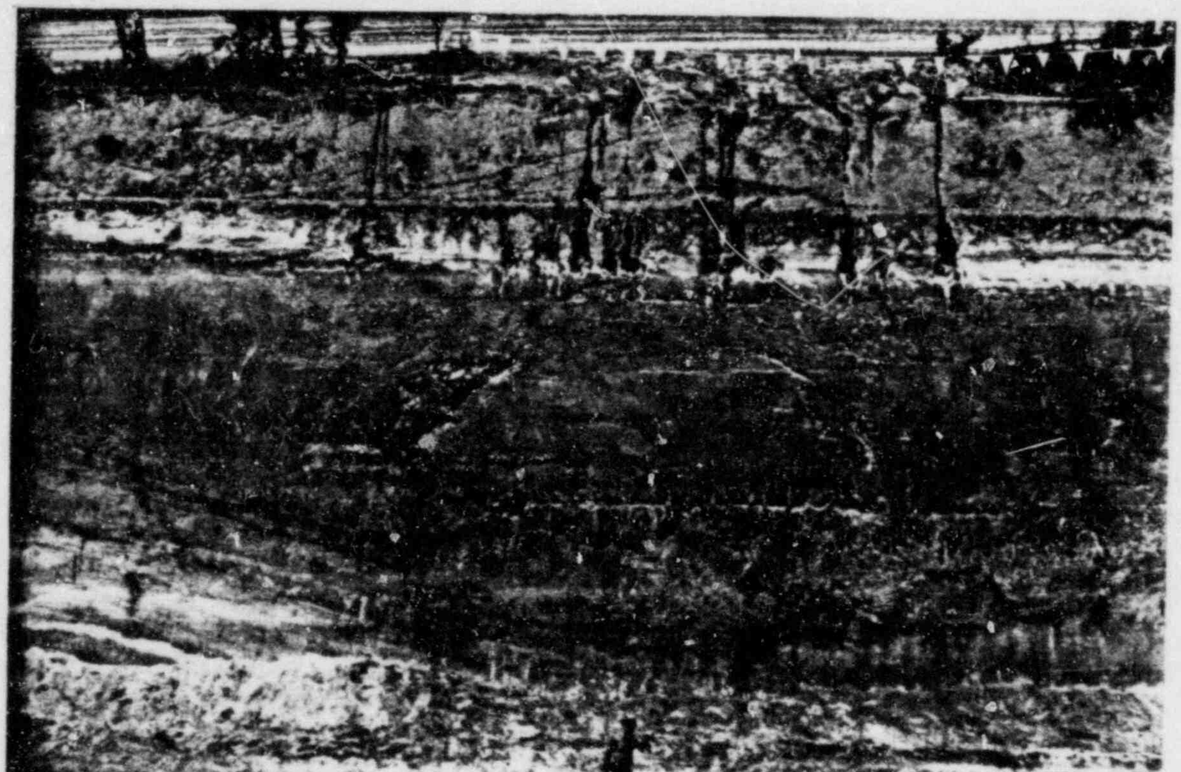


Figure 7 — Arcuate faults, fractures and clastic dikes over center of depression; west wall — Station 430 to 490.

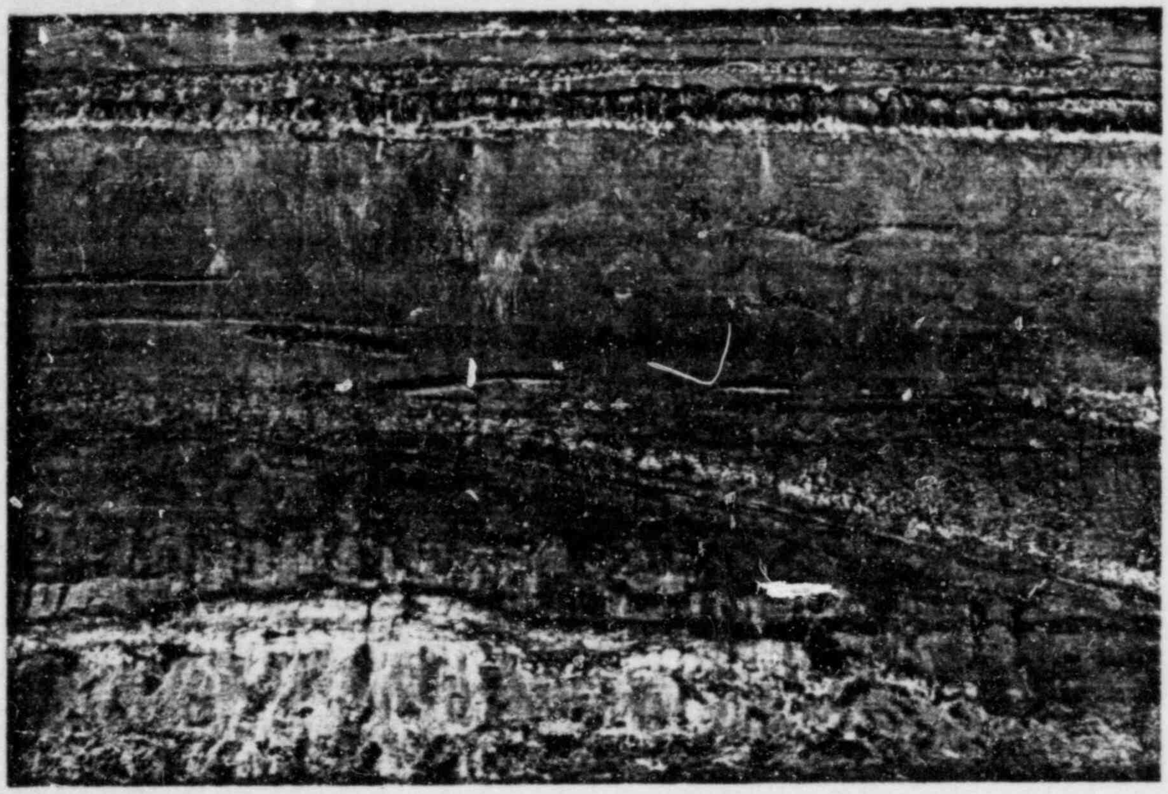


Figure 8 — Clastic dikes in upper part of Unit H; east wall — Station 570 to 610. Dikes generally decrease in density downward. Where dikes extend into underlying strata, they are coincident with minor offsets or fractures.

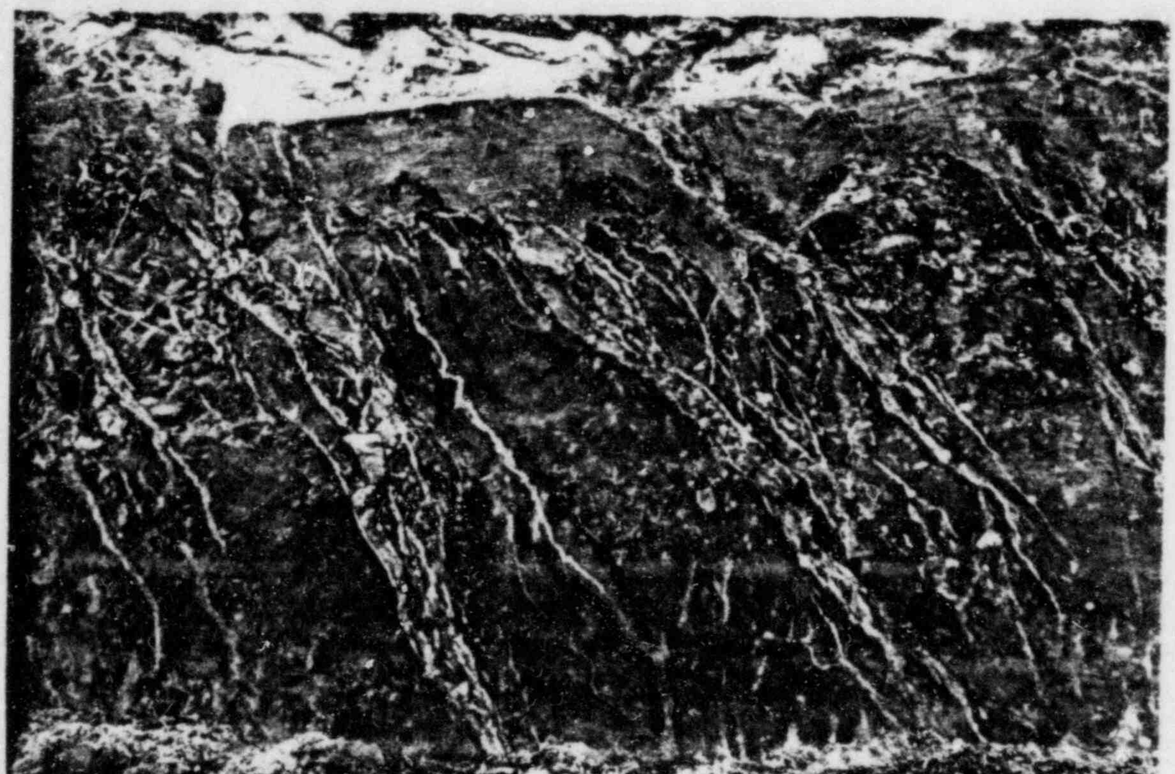


Figure 9 — Clastic dikes in upper part of Unit H; east wall — Station 220. Better developed dikes have an inner core of white clay. Dikes thin and generally pinch-out downward; upward they merge with brown soil B-horizon or are truncated by white eolian sand.